Available on CMS information server

CMS AN 2005/034

CMS Analysis Note

The content of this note is intended for CMS internal use and distribution only

30 November 2005

Jet Calibration from Dijet Balancing

Robert M. Harris

Fermilab, Batavia, IL, USA

Abstract

We describe dijet balancing to measure relative jet response as a function of pseudorapidity and to measure jet resolution. The analysis is based on reconstructed simulation data, without use of the Monte Carlo "truth" information on particles or partons. Dijet balancing in real collision data may be used to calibrate the real jet data, or may be used to test or calibrate the CMS simulation of jet data. Here we've performed a first rough demonstration of the dijet balancing technique using the CMS simulation of QCD dijets.

1 Introduction

Dijet balancing can be used to measure relative jet response and resolution from real jet data. The results can be used to calibrate the data or compared with Monte Carlo data to test or calibrate the full CMS simulation.

In dijet balance one jet is required to be in the barrel. The other jet is called the probe jet. Conservation of momentum for a 2 $\rightarrow$ 2 process requires they have the same p_T.

The mean of the p_T difference between the two jets measures the response difference of the probe region to the barrel. The RMS of the p_T difference measures the jet resolution.

Only reconstructed data is needed for the measurement. No Monte Carlo "truth" is needed. Comparison between real and simulated jet data tests our understanding of the detector and jet reconstruction.

Dijet balancing has a rich history at hadron colliders. It was first introduced at CERN over 20 years ago in a 1983 paper from UA2 [1]

> "The measurement of p_T^{jj}, the sum of two large and approximately opposite vectors, is sensitive to instrumental effects . . ."

Dijet balancing is used by both CDF [2] and D0 [3] at the Tevatron. Both experiments measured jet response as a function of η using jet data, and then used the measurement to form the jet corrections as a function of η. Some analyses measured the jet resolution using the data, and used the resolution to unsmear (deconvolute) measured distributions to obtain true distributions. We believe dijet balancing will be an essential tool for jet calibration at CMS.

2 Simulation and Reconstruction

All plots in this note are made from a sample of DC04 QCD events [4] at Fermilab, simulated with OSCAR 2_4_5 and reconstructed with ORCA 8_7_1. A total of 210,000 events were used, from 21 samples each consisting of 10,000 events sub-samples in contiguous intervals in generator level of p_T spanning from 0 to 4000 GeV: 0-15, 15-20, 20-30, 30-50, 50-80, 80-120, 120-170, 170,230, 230-300, 300-380, 380-470, 470-600, 600-800, 800-1000, 1000-1400, 1400-1800, 1800-2200, 2200-2600, 2600-3000, 3000-3500 and 3500-4000. EcalPlusHcalTowers were reconstructed with the default CMS algorithm which has a cut at 0.5 GeV on the energy in each HCAL compartment. Jets were reconstructed with the default CMS algorithm: iterative cone algorithm, a cone size of $R = 0.5$, no seed threshold, 0.5 GeV E_T tower threshold, and E-scheme method of constructing jet four vectors. All reconstructed jets with $p_T > 10$ GeV were written to a root tree by RecJetRootTree.cpp, along with a single multiplicative correction factor for the jet Lorentz vector obtained from jetCalibV1 [6]. The correction is designed to give a Lorentz vector from the particles in the jet cone before pileup. The sample consists of a mixture of QCD events and minimum bias events corresponding to the anticipated number of multiple interactions for a luminosity of 2×10^{33} cm^{-2} s^{-1}. Each sub-sample has a weight corresponding to the generated cross section per event for that sub-sample. The weight's vary significantly from sample to sample, ranging from 5.5×10^5 pb for the 0-15 sample to 9.7×10^{-9} pb for the 3500-4000 sample. When making a histogram all events from each sub-sample are used along with their corresponding weight, and all errors are calculated taking into account the weights.

3 Dijet Balancing for Response Measurement

In dijet balancing the two jets with highest p_T in the event (the leading jets) are found and events are selected requiring at least one leading jet to have $|\eta| < 1$ (the barrel jet). To measure jet response versus η the other leading jet (the probe jet) may be at any value of η. When both leading jets have $|\eta| < 1$ the one that is designated the probe jet is chosen randomly so that each jet has equal chance of being the probe. For each range of dijet p_T, defined by

$$p_T^{DIJET} = (p_T^{PROBE} + p_T^{BARREL})/2,$$

we divide the data into bins of probe jet η and measure the distribution of the dijet balance

$$b = (p_T^{PROBE} - p_T^{BARREL})/p_T^{DIJET}$$

Measuring b in a range of dijet p_T minimizes the bias in b. If we had instead measured b for a range of p_T^{BARREL} then p_T^{BARREL} would always be biased high due to effects of resolution on the steeply falling jet p_T spectrum, which would bias b to be very low.

The relative response, defined as the fractional difference between the jet response in the probe region and the jet response for $|\eta| < 1$, is then $r = 2\bar{b}/(2 - \bar{b})$, where $\bar{b}$ is the mean value of the dijet balance distribution. The reader may notice that the relative response is equivalent to

$$r = (p_T^{PROBE} - p_T^{BARREL})/p_T^{BARREL}. \tag{1}$$

It is important to note that we do not measure the distribution of r in order to find its mean value. Instead we measure the mean value of the b distribution, which is unbiased for a fixed range of dijet p_T, and transform it to the mean relative response using $r = 2\bar{b}/(2 - \bar{b})$. This procedure avoids correlations between the numerator and denominator in equation 1 for a fixed range of dijet p_T; correlations that are observed to bias the r distribution to the high side of response and result in a mean value of response that is too high.

In Fig.1 we show a simulation of the measurement of response from dijet balancing at fairly low p_T, where large variations in relative response are clearly seen as a function of η. We plot as a function of $|\eta|$, using z reflection symmetry in the simulation to increase the statistics. In Fig. 2 we show the relative response for larger values of dijet p_T. The detector response flattens with increasing p_T.

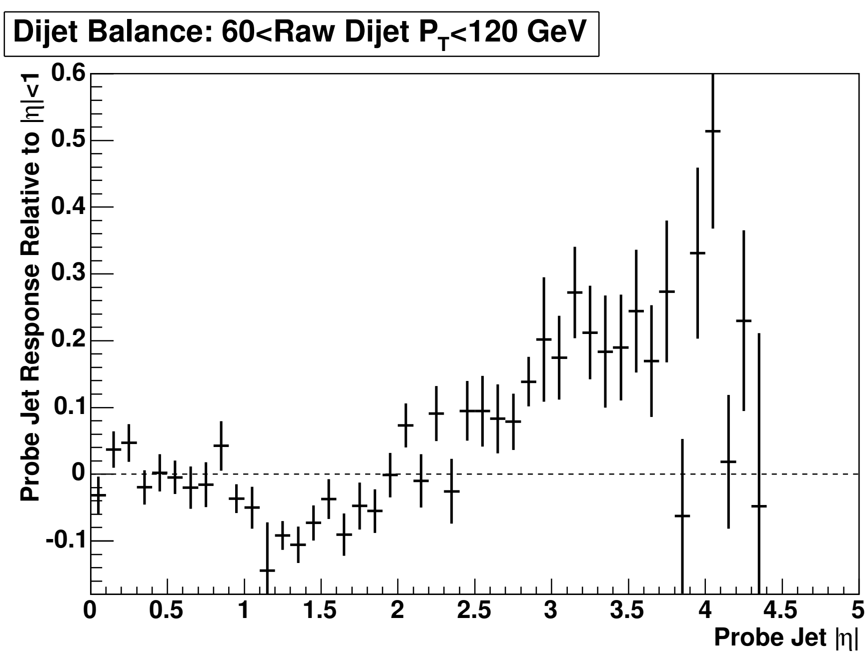

Figure 1: Response from Dijet Balancing for $60 <$ dijet $p_T < 120$ GeV.

The general pattern of the response variations were previously observed in studies using the MC truth [5], and here we show that they can be directly measured in data without utilizing MC truth. Hypotheses for the observed sources of response variations in η include [1)]

1. Noise in barrel, a fixed amount in energy, causing increaseing p_T with decreasing η.
2. A Barrel-Endcap transition region causing decreased response.
3. A general increase in response with η (increasing energy for a fixed p_T) due to calorimeter non-linearities resulting in better jet response at higher energy.
4. Low energy particles spiraling into the endcap due to the magnetic field, increasing the endcap response.
5. A large energy scale in the forward region.

With the exception of the well understood effect of noise in the barrel, we do not claim to understand the response variations present in these plots, or that these plots support the hypotheses above. We merely note that dijet balance is a tool for measuring response variations.

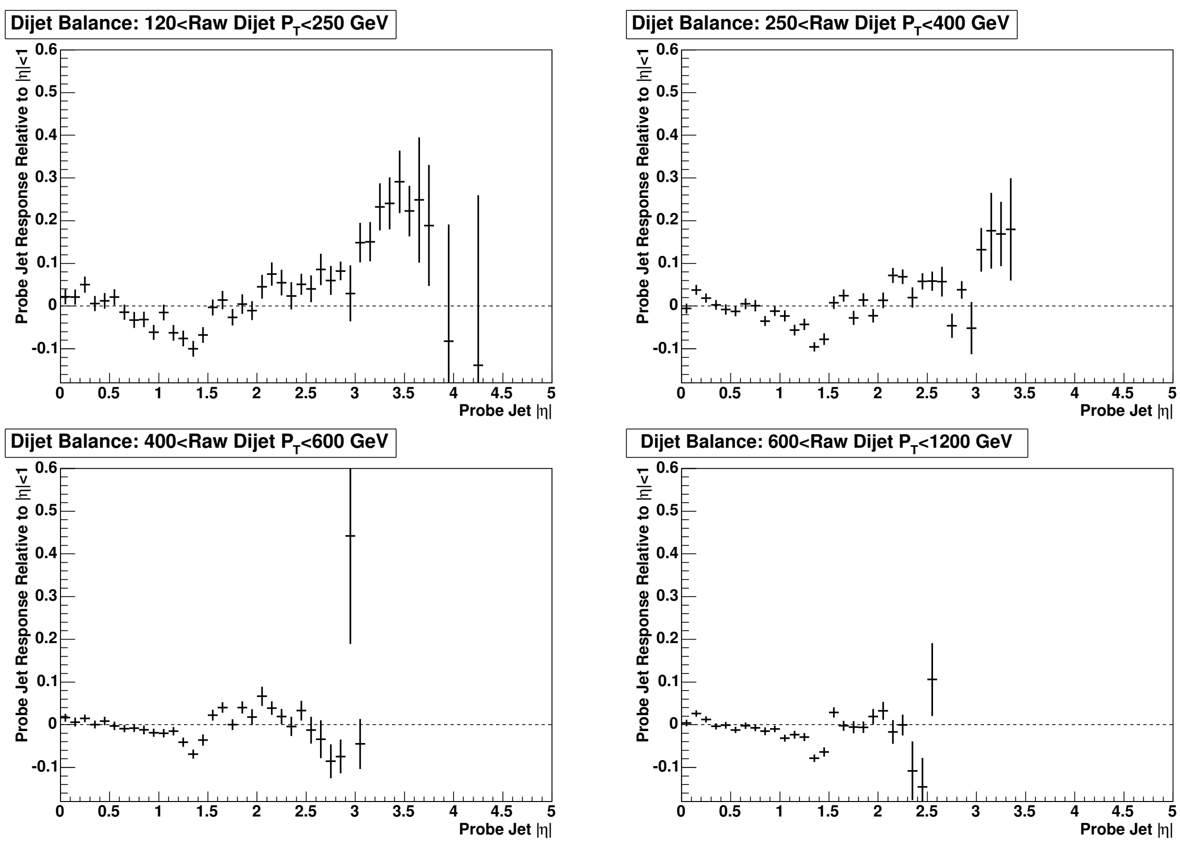

Figure 2: Response from Dijet Balancing of raw jets for 4 different ranges of dijet p_T.

[1)] We thank Salavat Abdullin for being the first to bring most of these hypotheses to our attention.

4 Dijet Balancing for Resolution Measurement

The jet resolution can be measured from the RMS of the dijet balance, σ_b. In Fig. 3 we show a dijet balance distribution in which both jets have $|\eta| < 1$. Hard QCD radiation, generally manifested as extra jets in the event, broadens the resolution and creates non-Gaussian tails, clearly visible in Fig. 3. We reduce the effects of QCD radiation to negligible levels by selecting events in which there are not any additional jets with $p_T > 0.1 p_T^{DIJET}$. After this cut the dijet balance distribution is Gaussian, as shown in Fig. 3.

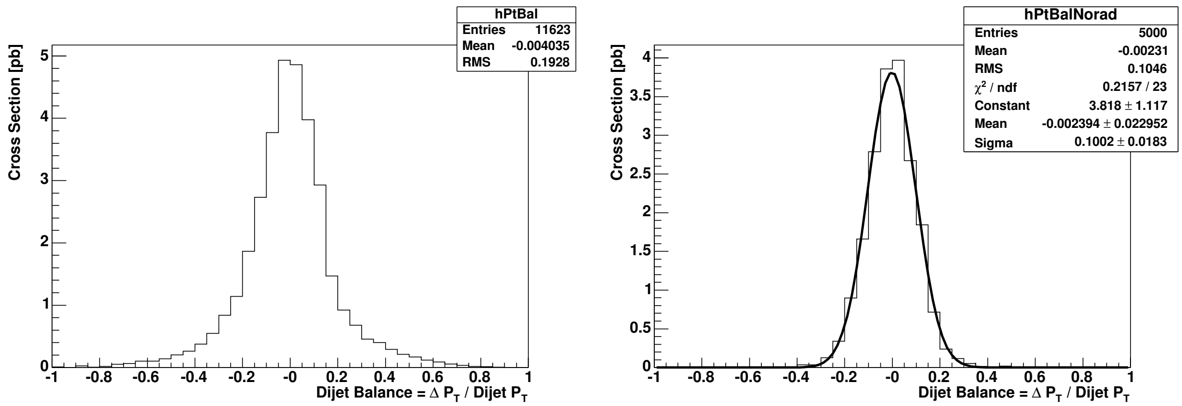

Figure 3: Dijet Balancing for Resolution Measurement. The distribution of dijet balance for raw jets with $600 <$dijet $p_T < 1200$ and $|\eta| < 1$ is compared for all events (left) and for events with no additional jets with $p_T > 0.1 p_T^{DIJET}$ (right). The right plot is fit with a Gaussian.

Each of the two leading jets contributes to the RMS, so the single jet resolution is given by $\sigma_b/\sqrt{2}$. In Fig. 4 we show the single jet resolution as a fraction of the dijet p_T for different values of dijet p_T and different cuts on the presence of additional jets. We note that a cut removing extra jets with $p_T > 0.1 p_T^{DIJET}$ appears adequate, since tighter cuts on the presence of radiation does not change the resolution significantly. Cuts on extra jets for the response measurement in the previous section are also possible, but reduce the statistics, and we do not see a significant change in the measured response when applying the $p_T > 0.1 p_T^{DIJET}$ cut.

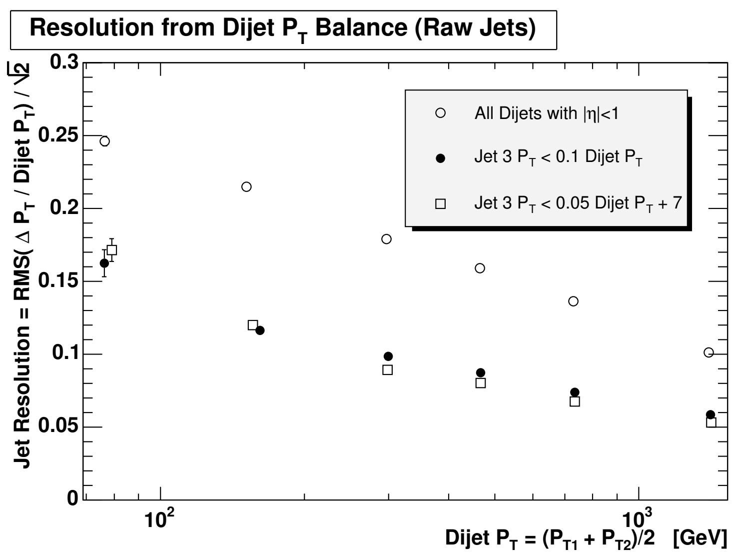

Figure 4: Jet resolution. Single jet resolution is shown as a function of dijet p_T for three different cuts on the presence of additional jets: no cut (open circles), default cut selecting events in which all extra jets have $p_T < 0.1$ dijet p_T (closed circles), and a tighter cut selecting events in which all extra jets have $p_T < 0.05$ dijet $p_T + 7$ GeV (open boxes).

5 Dijet Balancing with Corrected Jets

We repeat the dijet balancing analysis with corrected jets. Fig 5 shows that the corrections flatten the response as a function of η, and do not have much effect on the jet resolution for $|\eta| < 1$. The jet resolution shown in Fig. 5 is approximately the same as that obtained using Monte Carlo truth [5].

The extent to which the corrections flatten the response as a function of η is a closure test on the jet corrections. This can be performed with any corrections as a test of their validity. We note that the jet corrections used were originally derived from a sample of data binned every 0.25 in jet $|\eta|$ [6], and this measurement is done in bins of width 0.1 in $|\eta|$, so the plot of corrected response versus $|\eta|$ may reveal fine features of detector response versus η that the corrections simply integrated over. An unintended illustration of the benefit of having a measurement technique to test the level of validity of the jet corrections.

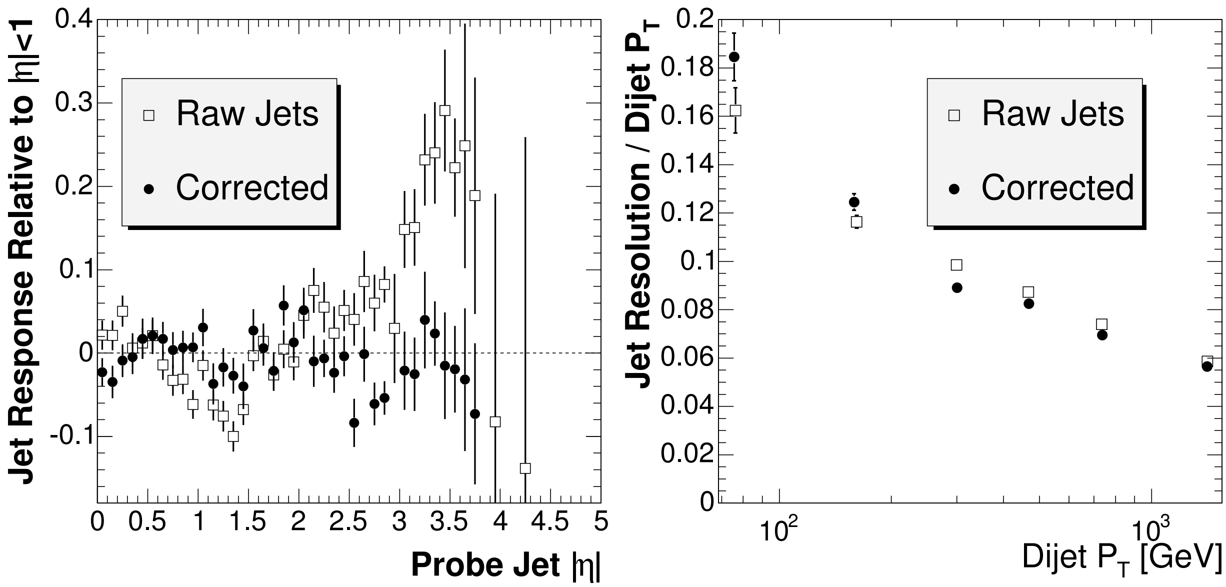

Figure 5: Results from dijet balancing. Left) Jet response as a function of $|\eta|$ for $120 <$dijet $p_T < 250$ GeV. Right) Jet resolution for $|\eta| < 1$ as a function of dijet p_T selecting events in which all extra jets have $p_T < 0.1$ dijet p_T. Both graphs compare raw jets (open boxes) with corrected jets (solid circles).

In Fig. 6 we compare the relative response versus $|\eta|$ of corrected and uncorrected jets for increasing values of dijet p_T. Even after corrections the response is systematically low in the transition regions between the barrel and endcap, and between the endcap and forward. We also note that the dijet balance measurement has some systematic biases in the presence of differences in resolution between the jets measured. When conducting a measurement on a sharply falling spectrum, such as our QCD sample, the region with poorer resolution will inherently be biased to larger response in a dijet balance measurement, simply because lower p_T particle level jets in this region fluctuate up into higher p_T reconstructed jets in the calorimeter, and causes the dijet p_T threshold to be satisfied. The balance measurement then assigns higher response for this jet that fluctuated up. This bias may also be contributing to the deviation from flat response for the corrected jets. When we ultimately have a real sample of data to correct, and test the corrections with dijet balance, we can compare this corrected dijet balance distribution to the same distribution from the Monte Carlo to help resolve any biases.

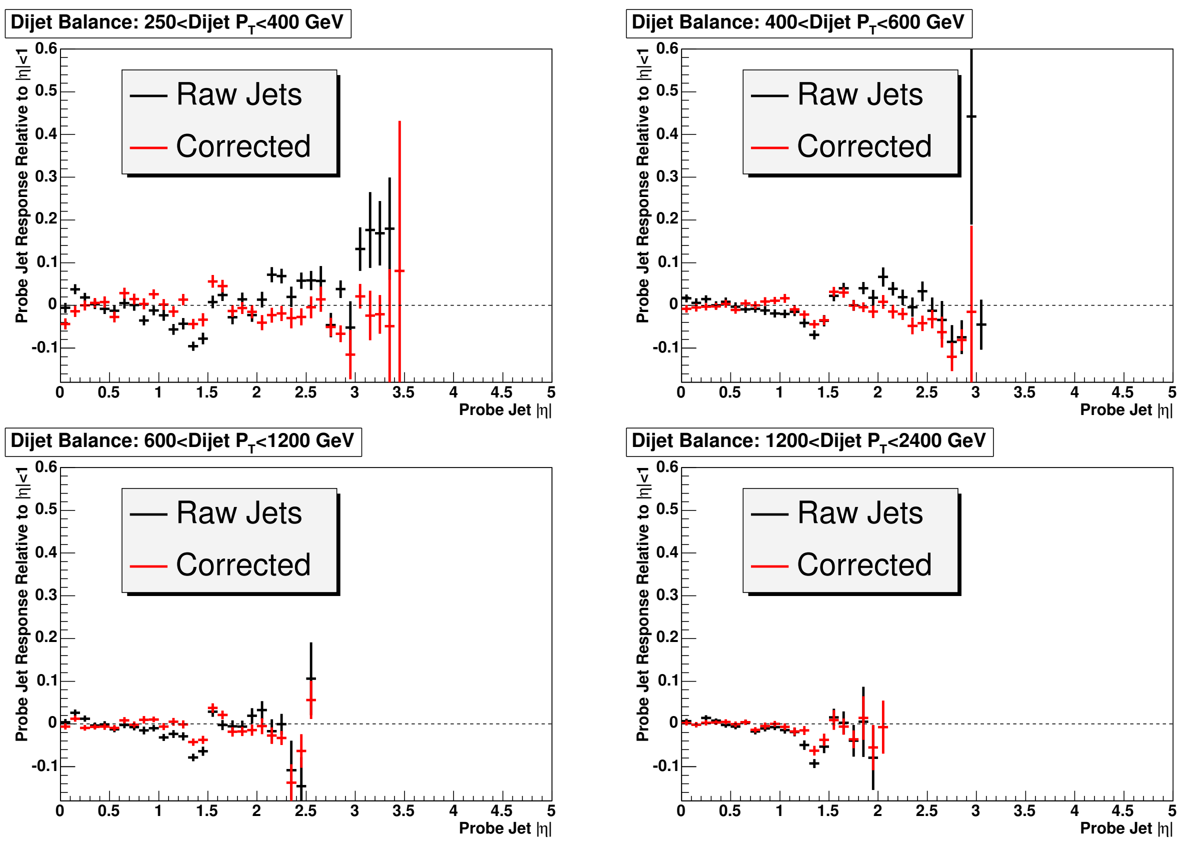

Figure 6: Response from Dijet Balancing of corrected jets (red) and raw jets (black) for 4 different ranges of dijet p_T.

6 Dijet Trigger and Jet Calibration

We define a dijet trigger as one that selects events above a threshold in dijet p_T. The primary motivation for a dijet trigger is to increase the trigger efficiency for dijet balance studies. A dijet trigger will provide the highest possible statistical precision for the measurement of the jet energy scale as a function of pseudorapidity. A dijet trigger will also allow the smallest possible time to accumulate a sample of size needed to perform this jet calibration. This may reduce the amount of time between jet calibrations used for analysis purposes, or more ambitiously for the trigger itself.

In our dijet balance analysis, to define the average jet p_T at which this response difference is measured, without biasing one jet or the other, the analysis always bins the data in the dijet p_T. When the analysis is done with a single jet trigger most of the data must be thrown away, as the cut on a single jet p_T introduces a significant trigger bias on the measurement of the difference of the two jet p_T, and an unbiased cut on the dijet p_T must be placed at a significantly higher value than the single jet p_T. In contrast, if a dijet trigger is used, the data is already selected in the dijet p_T, and practically all of the data may be used for dijet balance studies.

Dijet balancing can be used to derive calibrations as a function of η based solely on the data. The errors shown on the response in Fig. 5 correspond to a QCD sample of approximately 10^4 events. If an efficient trigger can be deployed with a dijet p_T threshold of 120 GeV/c prescaled to an HLT rate of 2.5 Hz, calibration measurements with the precision shown in Fig. 5 may be made from one hour of data taking. One day of data taking would be enough to calibrate the relative response of the detector to jets with a statistical error of 0.5% in the barrel and 2% in the endcap. These data could be further used to monitor the stability of jet response versus η, and provide daily calibrations to HLT triggers that require stable and uniform jet response.

7 Conclusions

Dijet balancing of reconstructed jets in the CMS data can be used to understand jets without relying on Monte Carlo truth information. Dijet balancing can be used to measure jet response relative to the barrel as a function of η. Dijet balancing can also be used to measure jet resolution. Comparison of dijet balance in the data and the Monte Carlo can then be used to set systematic uncertainties on jet reconstruction. Here we've performed a first rough demonstration of the technique in order to introduce it to the collaboration. We expect that future work will improve greatly on this.

References

[1] P. Bagnaia et al. (UA2 Collaboration), **Z. Phys C 20, 117** (1983) *"Measurement of Production and Properties of Jets at the CERN $\bar{p}p$ Collider"*.

[2] A. Bhatti et al. (CDF Collaboration), **hep-ex/0510047** (2005), *"Determination of the Jet Energy Scale at the Collider Detector at Fermilab"*.

[3] L. Babukhadia, D. Elvira (D0 Collaboration), **D0 Note Number 003554** (1998), *"Method to Test the Jet Energy Scale Using Transverse Momentum Balance"; B. Abbott et al. (D0 Collaboration),* **Nucl. Instrum and Methods A424***, 352-394 (1999); A. Goussiou (D0 Collaboration),***Fermilab-Pub 99/264-E***, "New Showering Correction for the Jet Energy Scale at D0"*

[4] DC04 QCD dataset production described at http://cms00.phys.ufl.edu/cms/DC04/PCP/.

[5] A. Heister, O. Kodolova, V. Konoplianikov, S. Petrushanko, J. Rohlf, C. Tully, A. Ulyanov, **CMS AN 2005/005**, *"Jet Reconstruction and Performance in the CMS Detector"*.

[6] R. Harris, *"Jet Calibrations from QCD Jet Sample"*, JetMET meeting on Oct. 6, 2004, http://agenda.cern.ch/askArchive.php?base=agenda&categ=a044286&id=a044286s1t1/moreinfo These jet corrections, available in the ORCA 8_7_1 package JetMetAnalysis/Jets, should be equivalent to those from reference [5] for reconstructed $p_T > 30$ GeV.